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Desalination of Sea Water by a Solar Distiller Assisted by a Heat Pump in the Tunisian South Climate

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Abstract: The increase in the population of Tunisia and industrial development posed with acuity during last. Without contribution of additional resources, water will likely to be increasingly rare. The desalination of sea water or brackish water has constituted the solution for several decades. Desalination by means of solar energy is a suitable solution to provide fresh water to a number of regions. In this study we propose a solar distiller assisted by a heat pump. The distiller uses for the evaporation of water and its condensation produced by greenhouse effect and the compression heat pump (CHP). The heat pump is composed of two major parts, the condenser, to heat water along with the sun and its evaporator, to condense the produced water vapour. The experimental tests were carried out as follows: orientation of distiller fixed in four directions (North, South, East and West) towards the sun and used a cover with a simple glass or double glass. The total number of configurations was 8. The results obtained show that the four configurations without CHP gave outputs less than 2 litres/m^2/day and a performance of 30%, but the configurations with CHP the distilled water flow increased to 12 l/m^2/ d (6 times more than previous one). The energetic efficiency reached to 90%. When the orientation of distiller varied with the sun, the internal temperatures increased and started to decrease only tardily at the end of the day. The temperature of distilled water exceeded 80°C. The cold surface of the evaporator of the heat pump was less than 30°C that made it possible to condense the water vapour produced and to keep a dry internal atmosphere with a relative humidity from 8-25%. The distilled water flow varied from 600-1700 ml/h/m^2. Under a solar flow from 700-800 W/m^2, the efficiency reached to 100%. The influence of salinity on the daily distillate produced flow was very less, 10% only. The quantity of saline water placed at the bottom of the distiller increased thermal inertia and consequently delayed the phenomenon of evaporation. It reduced the flow of distillate and the effectiveness of the process.

Key words: Simple Solar distiller • Hybrid solar distiller • Heat pump • Efficiency

INTRODUCTION

Tunisia is located on the southern rim of the Mediterranean basin. Like its neighbour countries, it is confronted by a problem of fresh water shortage. In fact, it has very limited water resources, aggravated by a large spatial and temporal disparity between southern and northern parts and fluctuations from year to year. In particularity the region of Gabès in the south of Tunisia. In remote rural communities, the problem of potable water remains unsolved. There are about 1.5 10^6 inhabitants and the distributed water volume reaches 19 10^6 m^3 per year, with an average specific consumption estimated at 45 l per capita per day, which is considerably lower than the national average (130 l per inhabitant per day). In addition, 8 10^6 m^3 of the distributed water has a high salinity, making it unfit for human consumption [1].

In the present study we propose a coupling of a compression heat pump with the solar simple distiller. This heat pump will be useful doubly:

- The condenser will contribute to the heating of water and thus to its evaporation especially the morning and in end.
- The evaporator will allow, while being cold, to condense most of the steam, the remainder (left tiny 5 to 10%) condenses under the glass.

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Our study relates to the experimentation and the modelling of a simple solar distiller (SSD) and of a hybrid simple solar distiller with a heat pump (SSDHP).

Technology Applications: There are processes of desalination being used Multi-Stage Flash (MSF) process that has been in use for the last 30 years. Seawater is pressurized and flashed in various chambers at lower pressures with a drastic reduction of the specific heat transfer [2].

Multi-effect desalination (MED) is a large scale evaporative process. Multiple effects in series running at lower pressure are used where the vapor from an effect is used to vaporize water in the subsequent effect. The major advantage of the MED process is its efficiency to produce more water per pound of steam used. The average capital cost of MED is 4.5 millions per MIGD of fresh water. However, production rate of MED plants is lower than MSF plants [3].

Reverse osmosis (RO) technology utilizes high pressure to permeate water with low total dissolved solids (TDS) through a semi-permeable membrane. Capital cost of RO plants averages 4.0 millions per MIGD [4]. This technology has proved to be a viable technology which is characterized by significant reduction in energy consumption and can produce potable water with salt content of about 500 ppm in a single stage plant at a competing cost [5].

Electro-Dialysis (ED), or the more modern Reversible Electro-Dialysis (EDR), in which ions are forced to pass by means of DC electrical power through semi-permeable membranes into concentrated streams leaving behind dilute salt solutions, [6] were considered to be a promising technique.

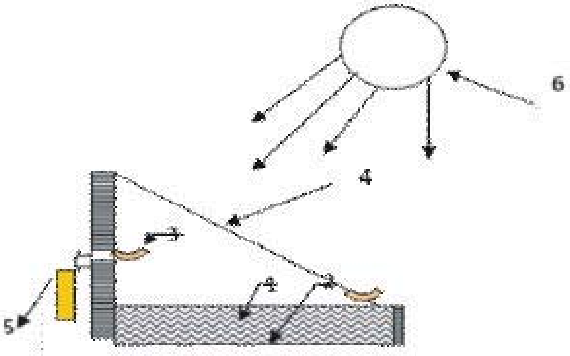
These technologies, however, have been designed and constructed to large-scale production and industrialization, which sometimes causes environmental and energy problems.

On the other hand, solar distillation is one of the most preferable processes for a clean environment and that uses renewable energy in spite of lower productivity. The simple technology utilizing free natural energy contributes to desert technology on a small scale of water demand and is easy to integrate into a solar still with thermal applications [7], e.g., agriculture, biogas enhancement, or greenhouses [8]. Solar stills are usually classified into two categories [9]: a single-effect type and a multi-effect type that reuses wasted latent heat from condensation [10]. The integration between a solar collector and a still is classified into passive [11] and active [12] stills. Single-effect passive stills are composed of convectional basin, diffusion, wick and membrane types [13,14]. The validities of a still with cover cooling [15,16] and a still with a multi-effect type basin [17] have been studied. Complicated systems with a variety of solar stills are not applicable to desert technology.

Experimental Procedure: In our experimental work, tow models are used. The first one is called the SSD (Simple Solar Distiller) model, in which the water output is simply obtained by purely solar energy. This model works only on day. The second one is named the SSDHP (Simple Solar Distiller hybrid with Heat Pump) model. In this model, heat pump was used in order to increase the quantity of water output. This works by using both purely solar energy and heat pump, consequently it was used on day and night.

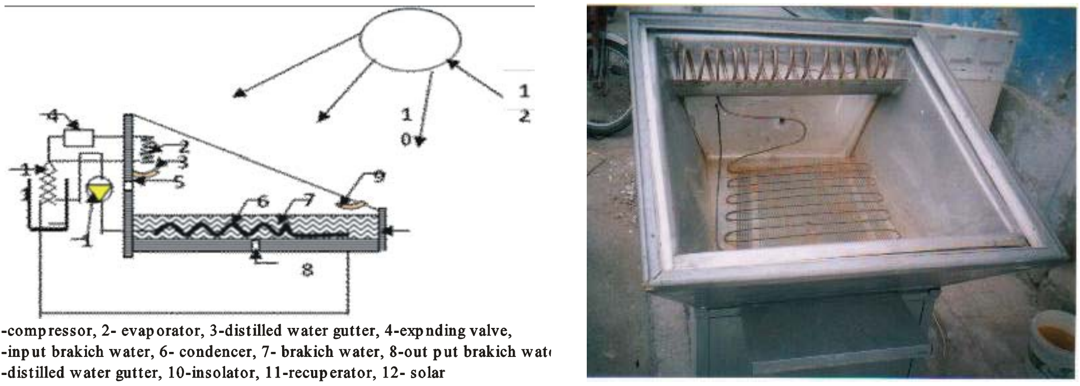
It should be noticed that, the condenser will contribute to the heating of water and thus its evaporation especially the morning and according to midday to compensate misses it sun. The evaporator will allow while being could, a more quantity of condensed water.

The SSD model: Figure 1 shows the schematic diagram of the SSD installation. It consists of a basin which is fabricated from fibre forced plastic materiel that accommodates the brackish water for a maximum depth of water which is fixed at 30 cm and is covered by two slopping covers. The height of the lower vertical side of solar still was kept at 60 cm and the area of the basin is 0.4 m^2. The operation of the still is very simple: the incident solar radiation is transmitted through the transparent glass cover to the water. As result, the water is evaporated and reached the glass cover and then collected at the distilled water gutter at condensed phase.



1- brakish water, 2-bassin, 3- distilled water gutter,
4- glass cover, 5- distiller water output, 6-solar

Fig. 1: Simple Solar Distiller SSD



1-compressor, 2- evaporator, 3-distilled water gutter, 4-expnding valve,
5-input brakich water, 6- condencer, 7- brakich water, 8-out put brakich wat
9-distilled water gutter, 10-insolator, 11-recuperator, 12- solar

Fig. 2: Simple Solar Distiller hybird with heat Pump SSD HP

The SSDHP Model: In order to produce more output distilled water, we added a heat pump to the SSD model. Figure 2 shows this model. A condenser is immersed in basin water to increase temperature of water and then evaporated quantity of water will increase. The condenser located near the upper region of the glass cover enhances the condensation of the water vapour and the refrigerant (R12), leaving the condenser is then introduced in a recuperate filled with fresh water in order to maintain the temperature of the refrigerant. Then the refrigerant enters the evaporator at low pressure inducing the condensation of water vapour. As a consequence, a more quantity of condensed water will be recuperated at the distilled water gutter. The process is done naturally.

Experimental Parameters: For the installation, we assigned the value (0) for which the SSD and the SSDHP plants are orientation towards the south, the value (1) periodically directional towards the sun (altazimutale continuation).

For the glass cover, the value (0) is given when a single glass cover is used and the value (1) is given when we used double glass cover. Similarly, the value (0) is given in absence of heat pump and the value (1) is given when the heat pump is used.

All temperature is measured by using sensors while distiller output water temperature is measured by a mercury thermometer. The distiller output is measured by a graduated test-tube.

The following parameters are measured every hour for the two models:

- Water temperature T_w,
- Vapour temperature T_{evp},
- Ambient temperature T_a,
- Distiller output m_{ex}.

Table 1: Shows the various tests that can be study

Position	Glass cover	Heat pump compression
0	0	0
0	0	1
1	1	0
1	1	1

Table 2: Values of C, n and heat transfer coefficients obtained for different inclinations of condensing covers

Values obtained	15°	30°	45°
C	1.418	2.536	0.968
N	0.148	0.158	0.209
Average h_{cw} (W/m^2°C)	1.670	2.440	2.010
Average h_{ew} (W/m^2°C)	13.360	16.930	12.840

Theoretical Consideration

Determination of Heat Transfer Coefficients: The evaporative heat transfer coefficient is given by the following expression:

$$h_{cw} = 0{,}01623.\frac{k_v}{L_v}.C(Gr.P_r)^n\left[\frac{P_w - P_{ev}}{T_w - T_{ev}}\right]$$

Analytical expressions for various parameters have been derived for SSD as well as SSDHP [18, 19]. Experimental validation has also been carried out by using following measured climatic parameters: solar intensity on the glass cover, ambient air temperature for typical days, namely, June, January on the solar stills located at Gabès, have been used in this model.

The distillate output (in kg) from the distiller unit can be obtained by the relation

$$m_{ev} = \frac{q_{ev}.A_w.t}{L} = \frac{h_{ew}.(T_w - T_{ev})A_w.t}{L}$$

The equivalent evaporative heat transfer rate q_{ev} can be derived from

$$q_{ev} = k.\,h_{cw}.(P_w - P_g)$$

Determination of Global and Interior Efficiency

Efficiency of SSS

The global efficiency is given by:

$$?_g = \frac{qe}{G.A_w.}$$

The interior efficiency given by:

$$?_i = \frac{q_e}{q_w}$$

Where $q_w = \alpha_t G\, A_w$ and $q_e = m_{ev} L_v$.

Efficiency of HSSHP

The global efficiency given by:

$$?_g = \frac{q_e}{(G.A_w + COP{\cdot}P).3600}$$

The interior efficiency is given by: $?_i = \frac{q_e}{q_w}$

Where: $q_w = \alpha_t GA_w + q\text{cond}$

$q\text{cond} = COP_{PAC}.P.$

RESULTS AND DISCUSSIONS

Figure 3 presents the variation of the solar intensity in function TSV for the month of June and July for four configurations, to study in way the intensity can reached equal values 850 W/m^2°C and this intensity is maximum with 14H.

Figure 4 present experimentally, of the hourly yields for SSD and SSDHP. The model of SSDHP gives an excellent output it can reach the value of 1.65 l /m^{2}h for (111) model. For the SSD model, the maximum flow is equal to 0.3 l/m^2°C.

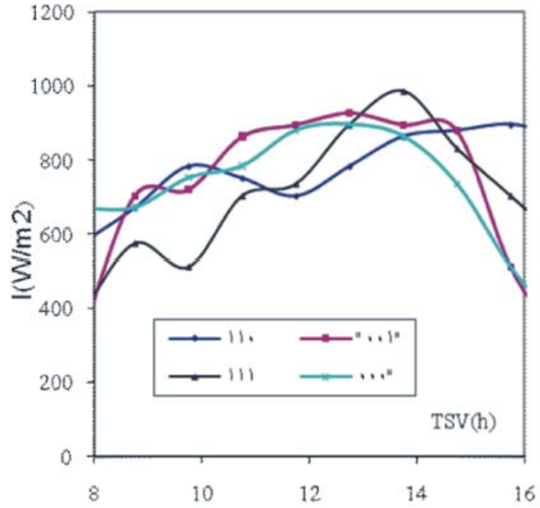


Fig. 3: Hourly variation of solar intensity

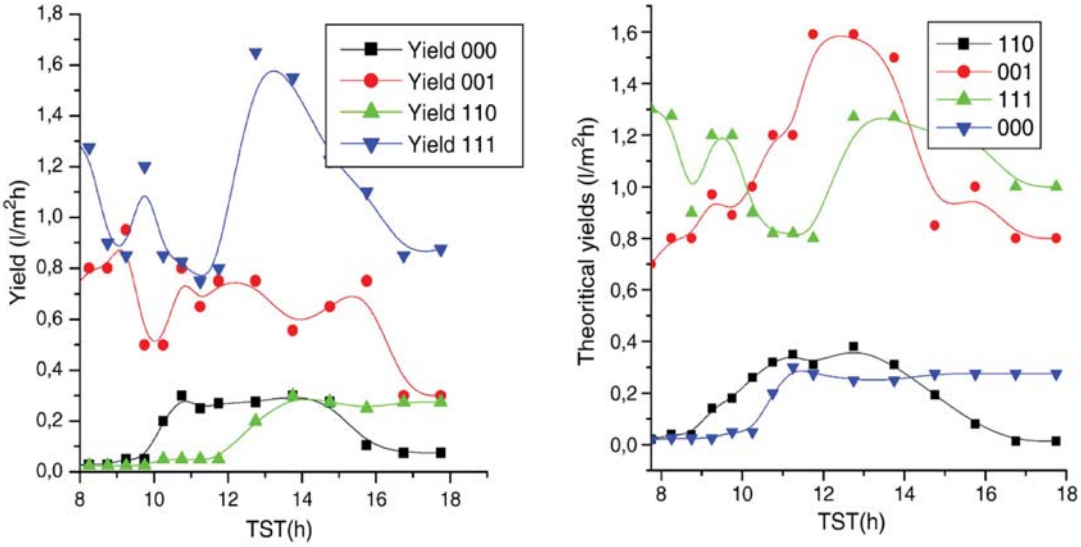


Fig. 4: Hourly variation of experimental and theoretical yields (l/m^{2}h)

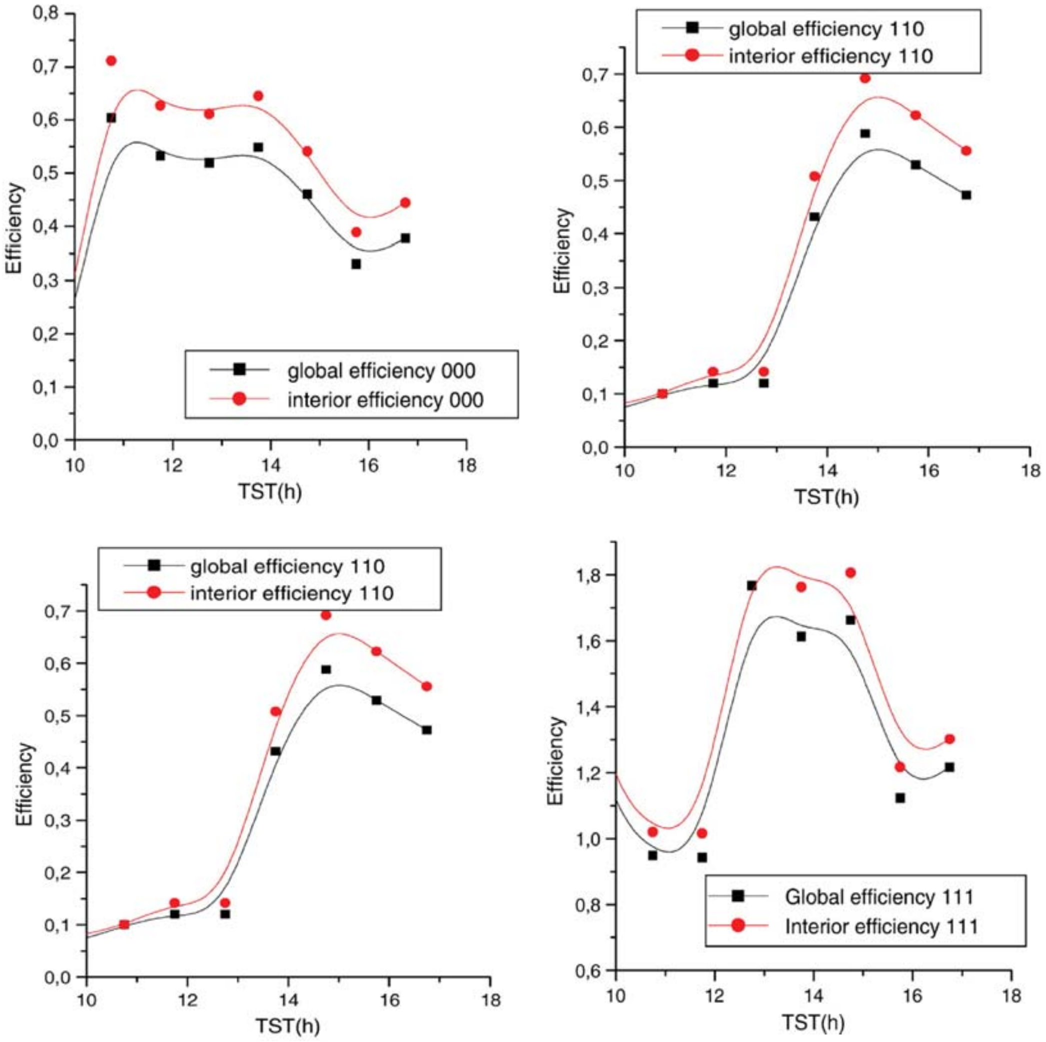


Fig. 5: Variation of the interior and global efficiency according to TSV for the different configurations

For the SSS configuration, the maximum flow is equal to 0.3 l/m^2°C. Theoretical results are comparable with the experimental ones, for statistical analysis, the error is more less for (001) and (111) (14%, 5.27%) than (000) and (110) (21%, 17%).

From Figure 5 it's clear that the global efficiency of SSS and HSSHP are increasing functions of true solar time however this growth attenuates for high values of the irradiation. It could be noticed that in the configurations (000), the internal efficiency is higher than the global efficiency, whereas for (001) and (111) configurations, the global efficiency becomes higher than the interior one. This was explained by the addition of the heat pump (one must take in account the quantity of (COP•P)).

Moreover, we can also notice that the global efficiency of the HSSHP model is definitely higher than that of the SSS because of its greater thermal inertia, which less quickly follows the variations of incidental solar energy.

CONCLUSION

The solar still for purpose of traditional greenhouse was taken as reference to show the performances of the solar still combined with a heat pump.

Our measurements showed an increase in going flow of 300 ml/m^{2}h with 1700 ml/m^{2}h by combining with a simple still for purpose of greenhouse heat pump with compression where the evaporator and the condenser are jointly used. As for the daily output, it passes from 2 l/m^2 to 12 l/m^2.

The average efficiency passes from 20% to 80%. In the configuration with heat pump, one observed low moisture of the air in the distiller; this is with the presence of the evaporator constituting a surface at temperature of weak dew. Thus, the vapor created in the still is quickly condensed.

For (110) and (000) configurations, the efficiency attained a maximum value of 0.8 as compared to the (111) and (001) ones, in the last cases, the maximumvalue is equal to 1.8. The efficiency is higher for (111) and (001) configurations than for (000) and (110) ones.

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SYMBOLS

Aw : Surface area, m^2
C : Unknown constant in the Nusselt number expression
Gr : Grashof number
G : The solar radiation (w/m^2)
q_{ew} : Rate of heat transfer by convection, (W/m^2)
q_{ev} : Rate of evaporative heat transfer, (W/m^2)
q_e : Heat flow used for the evaporation of water (W/m^2)
q w : Heat flow actually received by the water mass (W/m^2)
h_{cw} : Convective heat transfer coefficient from water to condensing cover, W /m ^{2}°C
h_{ew} : Evaporative heat transfer coefficient, W/m ^{2} °C
kv : Thermal conductivity of the humid air, W/m °C
L : Latent heat of vaporization of water, J/kg
Lv : Characteristic dimension of condensing cover, m
n : Number expression
m_{ev} : Distillate output, kg
Nu : Nusselt number
P_{ev} : Partial saturated vapour pressure at condensing cover temperature, N/m ^{2}
Pr : Prandtl number
P_w : Partial saturated vapor pressure at water temperature, N/m ^{2}
T_w : Water temperature, °C
T_{ev} : Inner temperature of condensing cover, °C
t : TSV True Solar Time interval, h
α_t : The fictitious absorption coefficient of the water mass (0.85).
η_i : Interior efficiency
η_g : Global efficiency
COP : Coefficient of performance of heat pump
P : Power of compressor equal 200 Watts